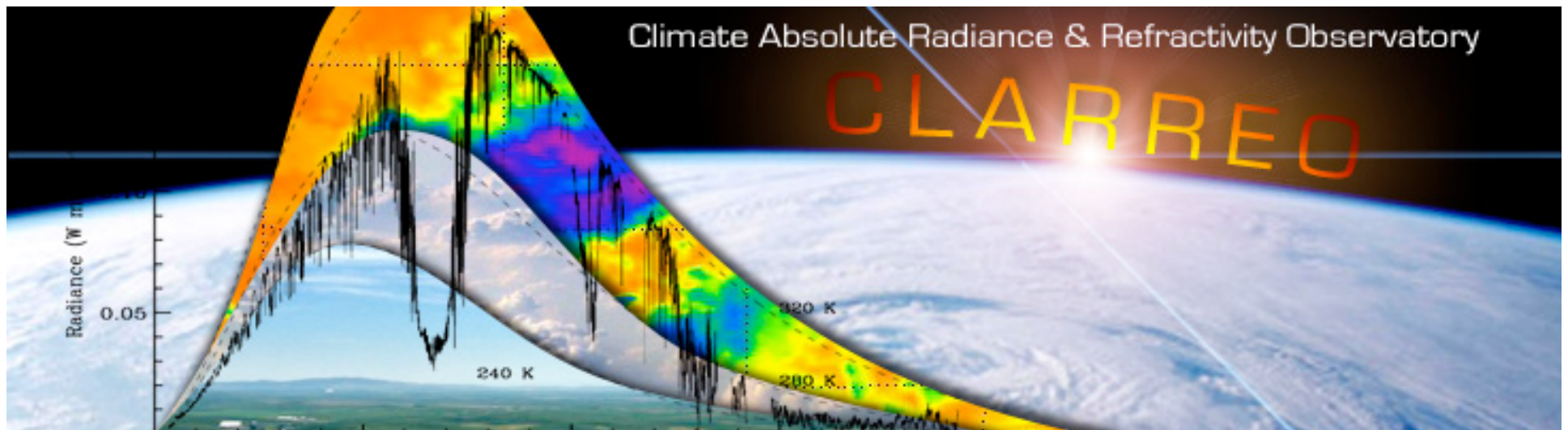


~~Solar~~ Shortwave Radiometry for Climate Benchmarking and Inter-Calibrations

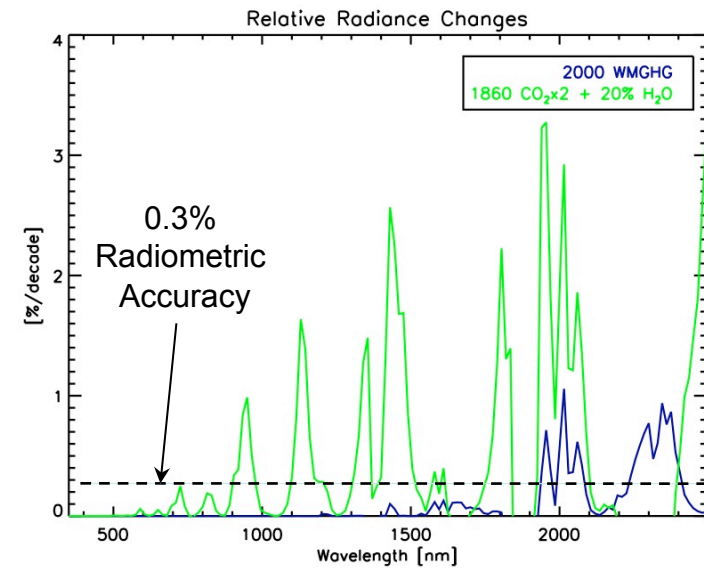
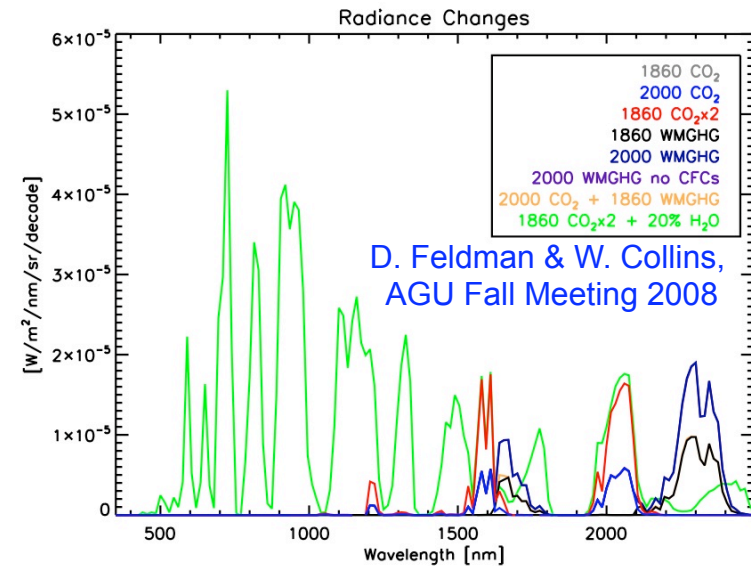
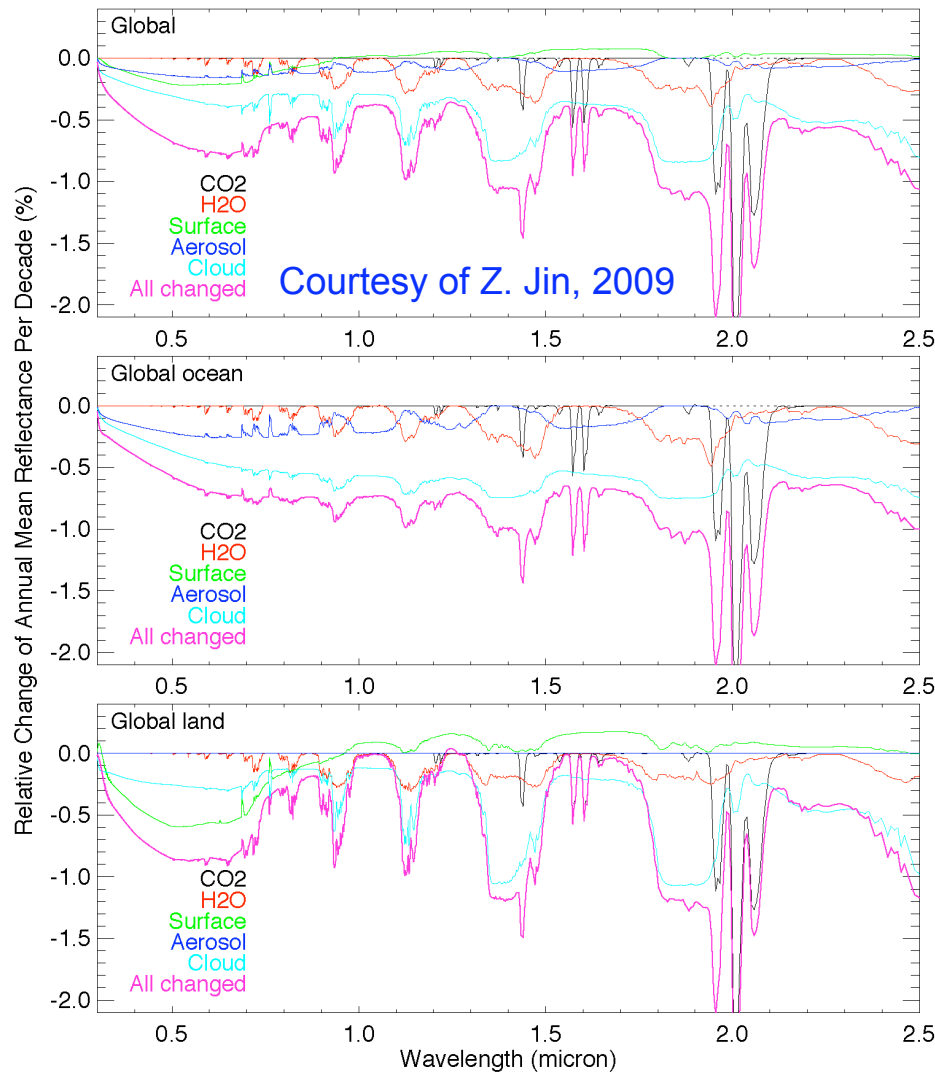
- With improved absolute accuracy in the visible and infrared, the Climate Absolute Radiance and Refractivity Observatory (CLARREO) will “benchmark” Earth’s climate
 - Shortwave mission component: Provide spectral Earth radiances with sufficiently high absolute accuracy to determine long-term climate change



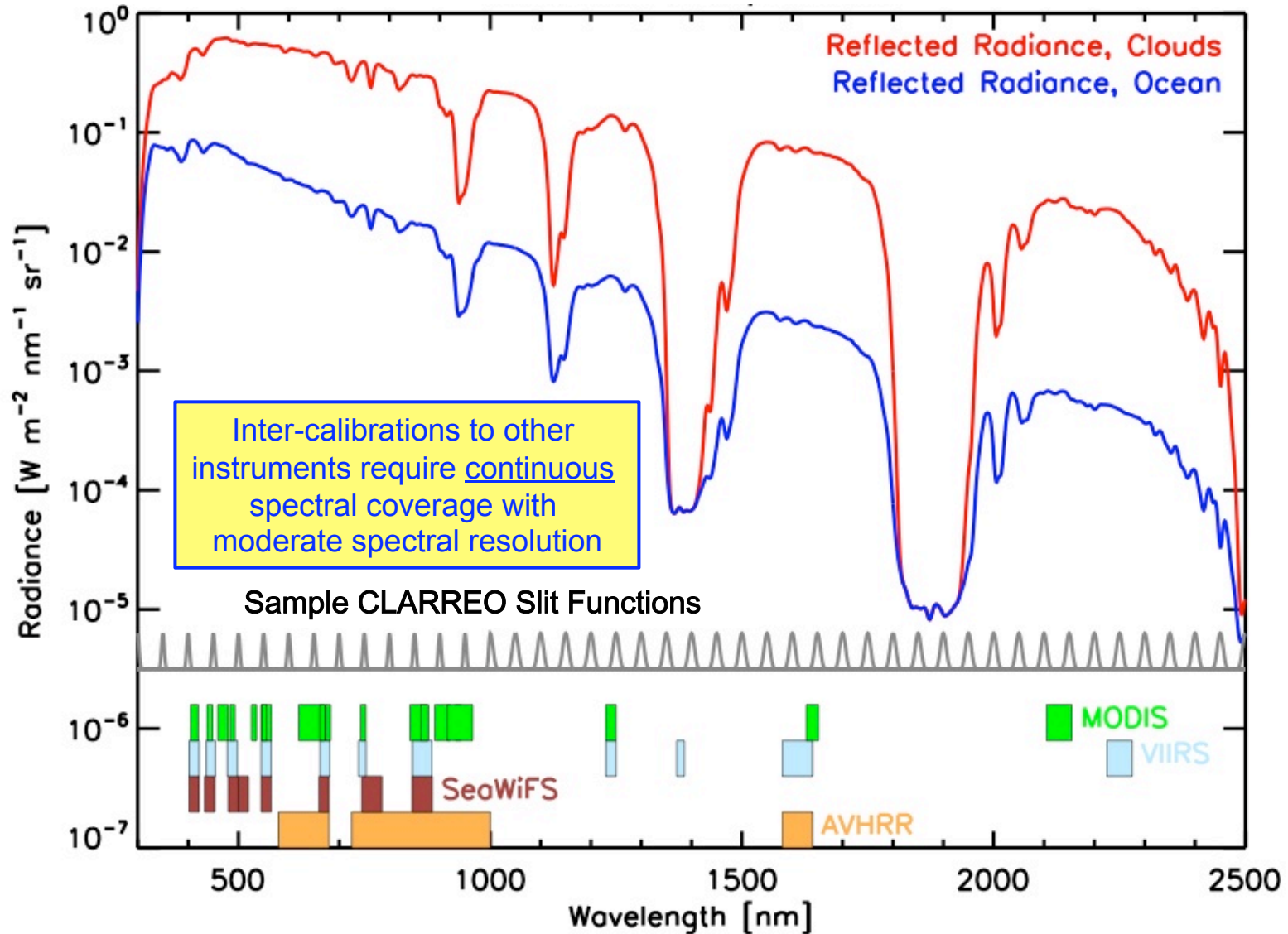
Greg Kopp, Peter Pilewskie, Ginger Drake, Joey Espejo,
Dave Harber, Karl Heuerman, Yolanda Roberts
Univ. of Colorado / LASP

Modeled Climate Sensitivity Drives DS Radiometry for SW

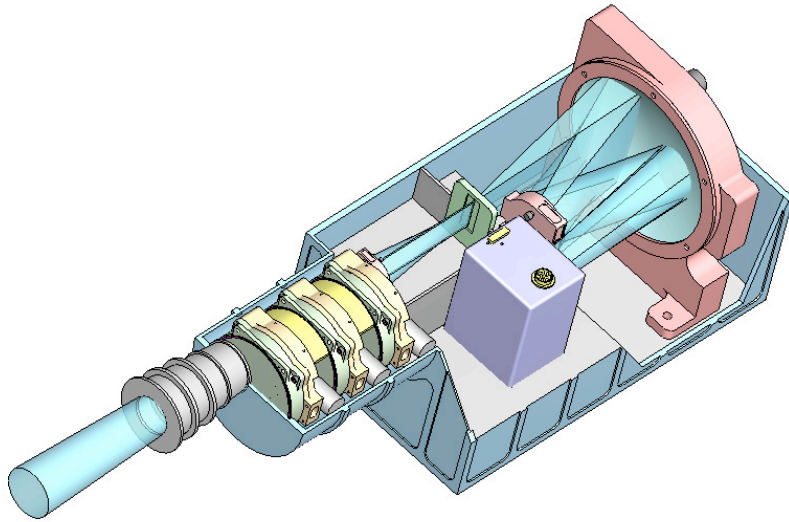
Solar Spectral Signal For 1 Decade Climate Change
(Relative change in percentage)



Need Continuous Spectral Coverage & Moderate Resolution



Earth-Viewing Shortwave Goals for IIP

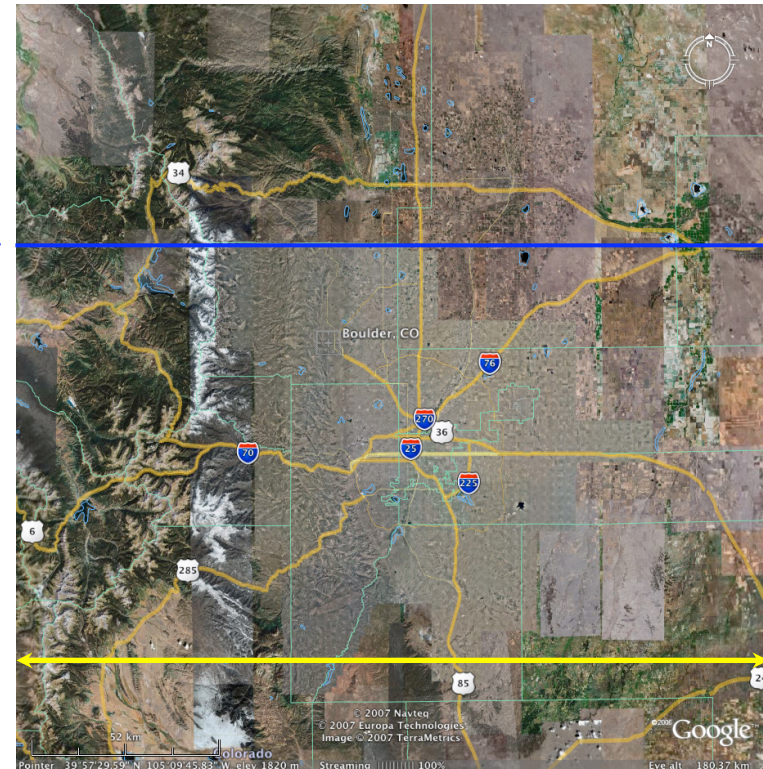


Shortwave spatial resolution
benefits CLARREO IR
measurements via cloud and water
identification (HISE 2009)

0.5 km (2.5 arcmin) IFOV

Hyperspectral Imager Requirements

Parameter	Value	Units
Spatial Resolution	0.5	km
Spatial Range (cross-track)	200	km
Wavelength (min)	300	nm
Wavelength (max)	2400	nm
Spectral Resolution	10	nm
Relative Std Uncertainty	0.2	%



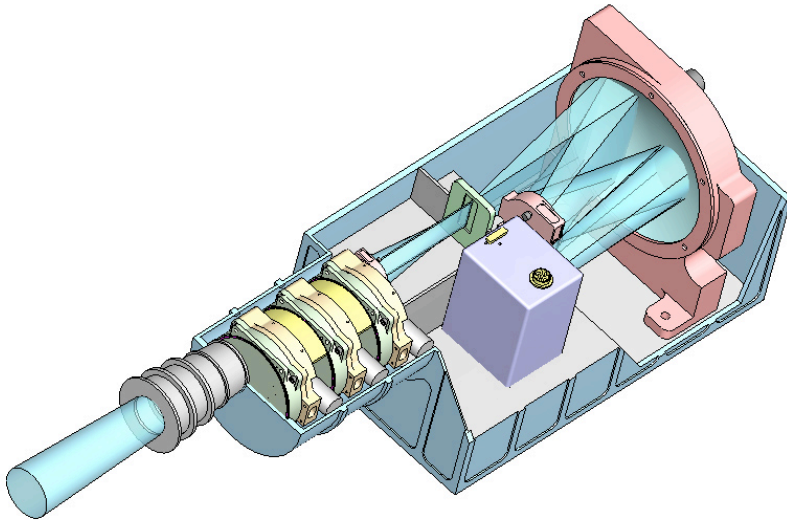
15° (180 km) (~370 pixels) Earth cross-track

Solar Cross-Calibration Achieves SW Radiometric Accuracy

Hyperspectral Imager Requirements

Parameter	Value	Units
Spatial Resolution	0.5	km
Spatial Range (cross-track)	200	km
Wavelength (min)	300	nm
Wavelength (max)	2400	nm
Spectral Resolution	10	nm
Relative Std Uncertainty	0.2	%

Cross-calibration from TSIS intended accuracy of 0.2% (1- σ).



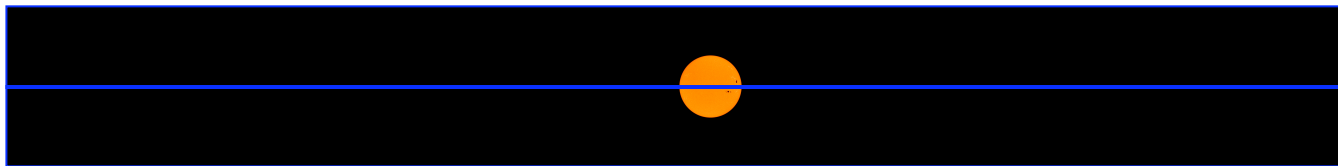
Ratio of solar incoming to outgoing radiances benchmarks climate in shortwave

Ratio of reflected (outgoing) to incoming solar radiation measured to <0.2% (1- σ).

One or two spatial/spectral imagers cover 300-1000 and 1000-2400 nm.

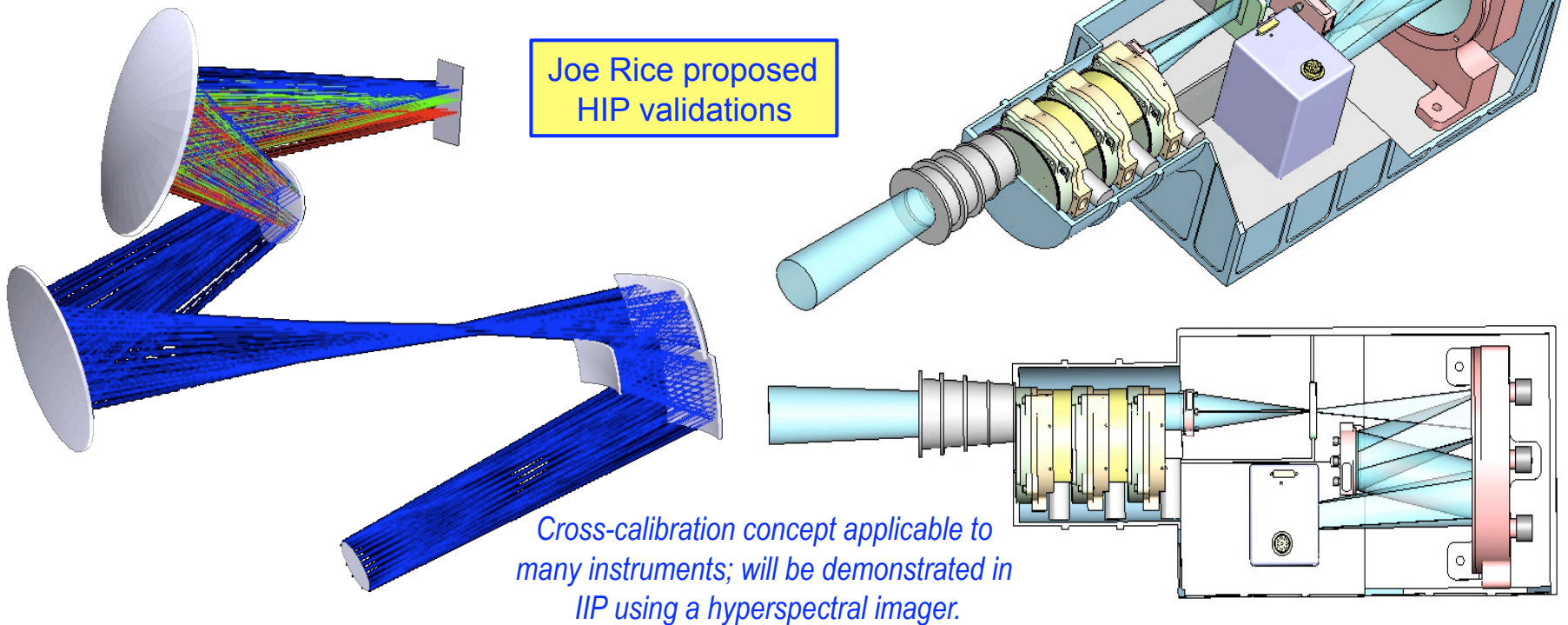
Small (~2-cm) telescope optics image the Earth onto spectrographs.

Radiance attenuation methods reduce intensity an accurately known amount, allowing cross-calibrations with Sun.

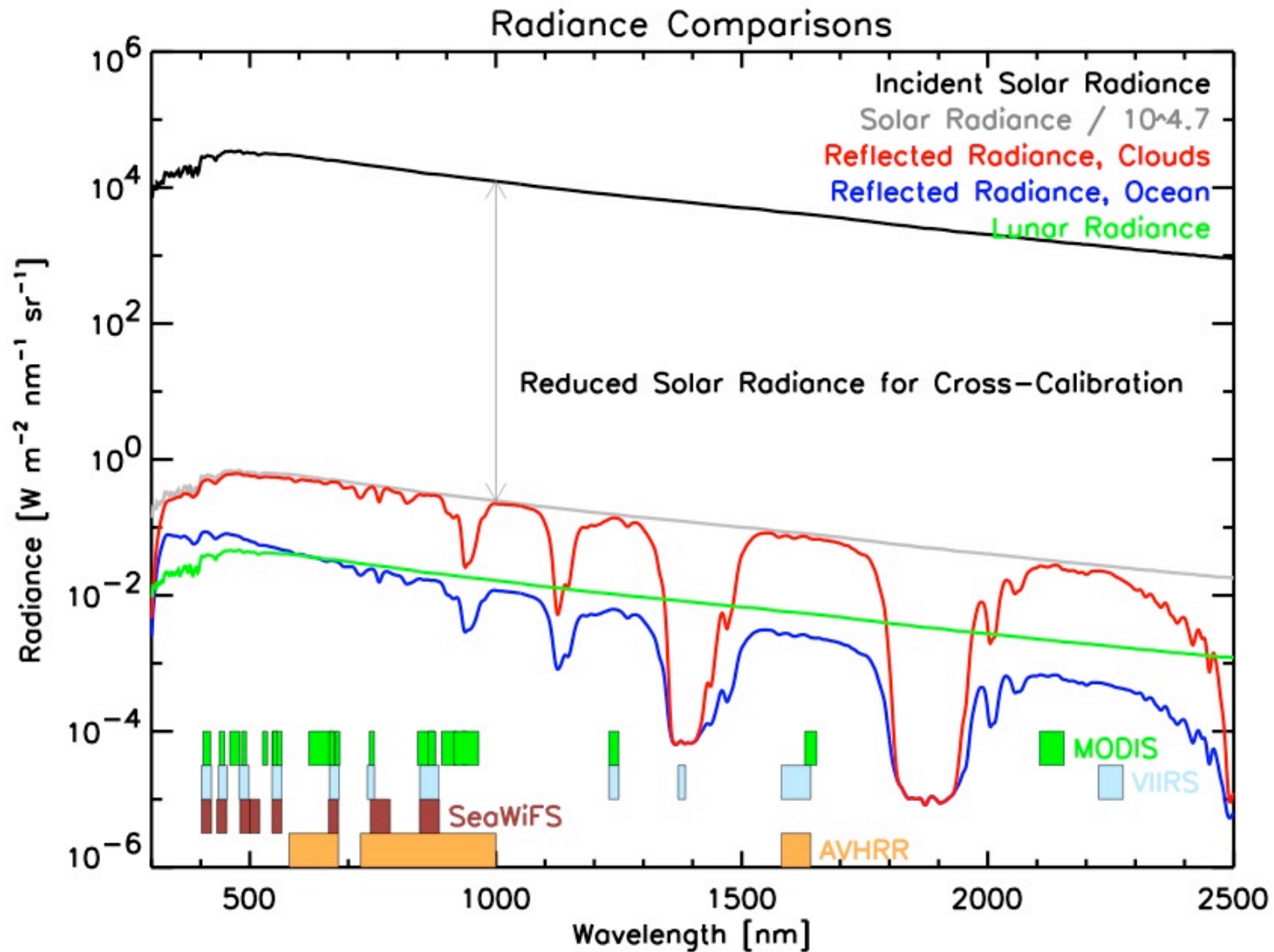


IIP to Demonstrate Cross-Calibration Approach

- **Intent** is to demonstrate cross-calibration capability from spectral solar irradiance to desired accuracies
- **Method** is to prototype a visible (Si-based) hyperspectral spectrometer with integrated attenuation methods and
 - Demonstrate accurate attenuation capabilities
 - Show a solar irradiance observation method



Need $\sim 10^{-5}$ Attenuation

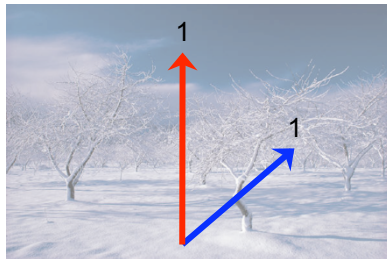


Attenuation Methods Demonstrated With IIP

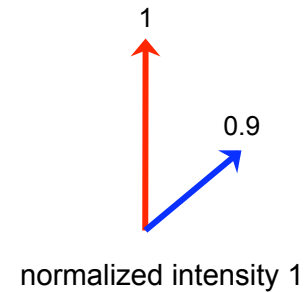
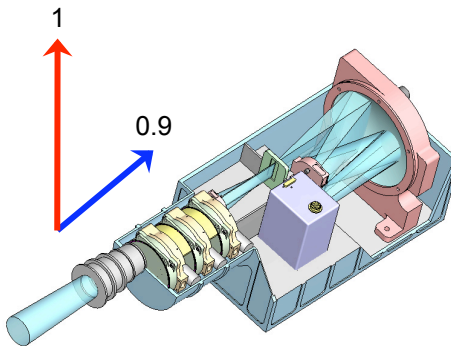
1. Aperture areas
 - *500- μm vs 2-cm diameter aperture attenuates light $10^{-3.2}$*
2. Integration times
 - *NIST aperture area calibration achieves desired accuracy*
 - *Diffraction limits attenuations achievable*
3. Filters
 - *High-speed and ROI read-out attenuate light 10^{-1}*
 - *Electronics limit attenuations achievable*
 - *Mechanical shutter may provide greater attenuations*
 - *ND filters attenuate light 10^{-1} to 10^{-2}*
 - *Filters are calibrated on-orbit via lunar observations*
 - *Same optical geometry as Sun*
 - *Signal-to-noise limits attenuations achievable*
 - *Lunar radiance variations may limit calibration time*

CLARREO Polarization Needs for Radiometry

- Polarization sensitivity must be $<0.5\%$ to meet radiometric accuracy
- Roughly, (scene polarization) \times (instrument polarization) = (error), so want
 1. Low instrument polarization sensitivity, and/or
 2. Known scene polarization states



unpolarized scene light



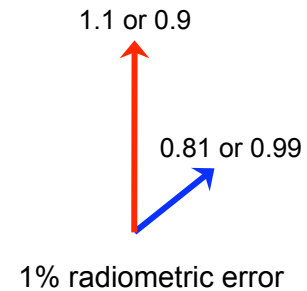
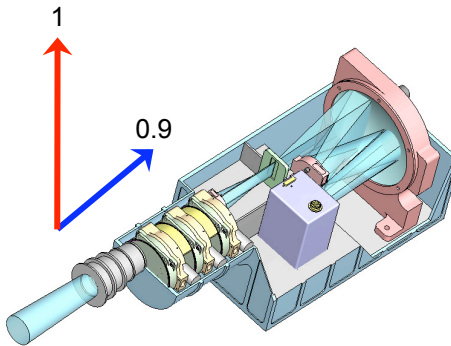
\times

10% instrument
polarization sensitivity

$=$



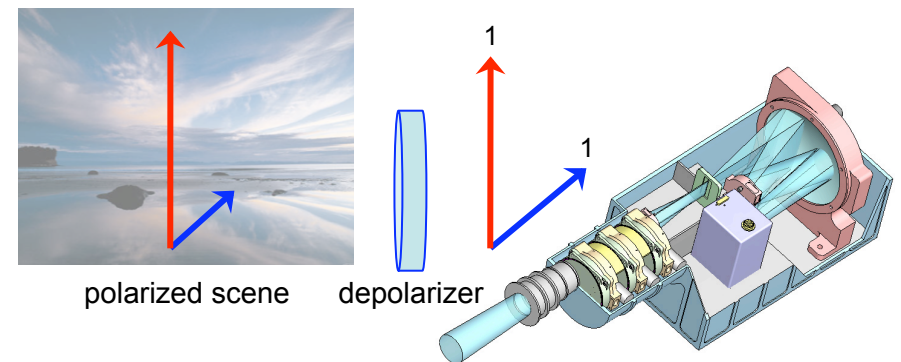
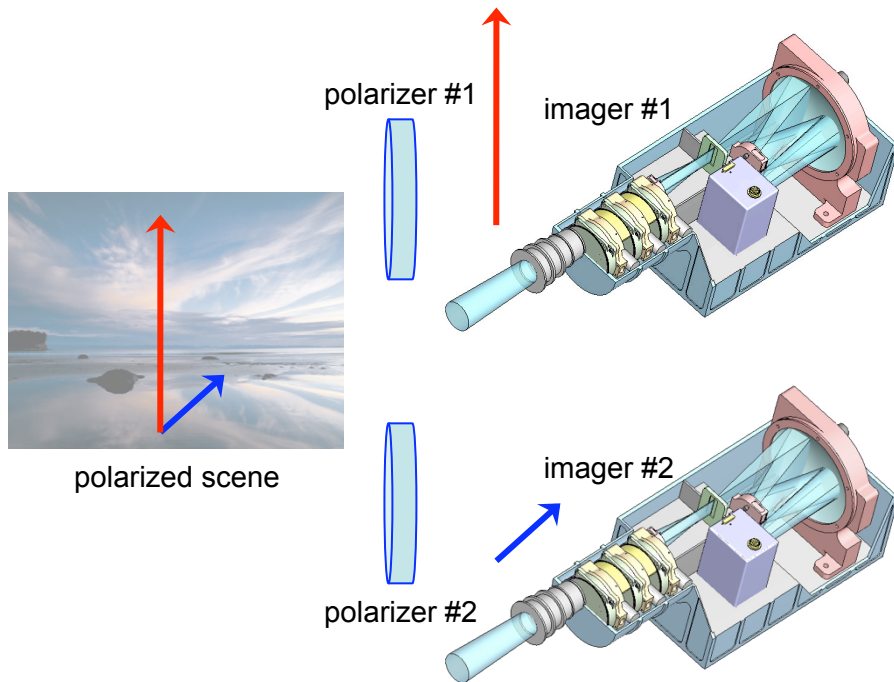
polarized scene light



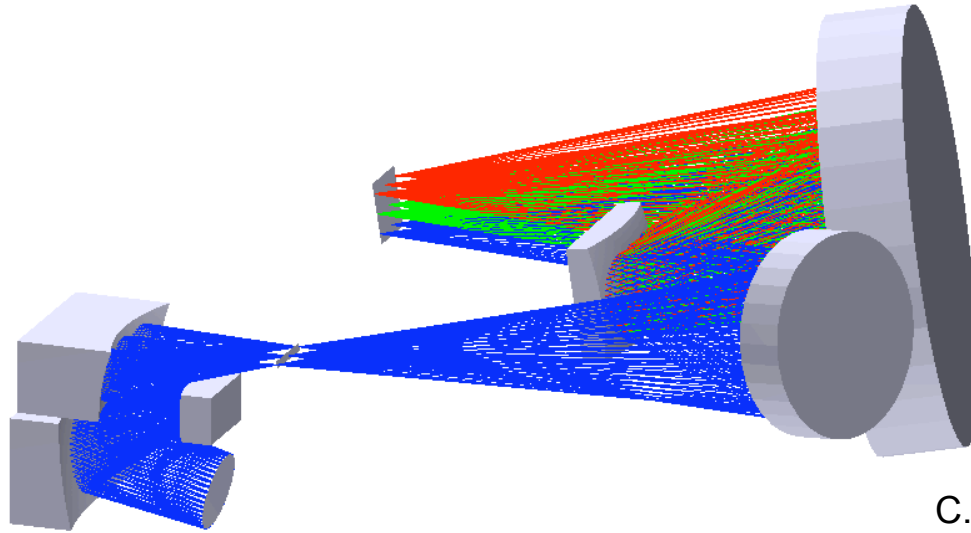
1% radiometric error

Methods of Knowing Scene Polarization

- Orthogonal polarizers
 - Define polarization state entering instrument
 - Offers additional science
 - Complex: May require dual instruments for simultaneous scene measurements in both states with accurate radiometry
- Depolarizer
 - Greatly reduces sensitivity to scene polarization state
 - Simple: Single depolarizing optic added to hyperspectral imager



IIP Optical Design Reduces Polarization Sensitivity



- **Partial Solution:** Rotate the Offner 90° with respect to the TMA
- This causes an equal number of TE and TM plane reflections for any input polarization

Distribution of Degree of Polarization
PARASOL 2006.10.02

C. Lukashin, B. Wielicki, D. MacDonnell, LaRC

Distribution of DOP (global):

PARASOL data: 12 days of 2006 (one per month, “cross-track” sampling)

- Offner rotation plus incidence angle changes result in a 0.2% polarization sensitivity at the detector
- Results in <0.04% radiometric error
 - Most scenes <20% polarized
 - Polarization orientation known
- *Validate & track polarization sensitivity via solar observations using orthogonal polarizers*

Relative fraction of data (%) with DOP(490 nm) < X (fractional):							
Zone	< 0.05	< 0.1	< 0.2	< 0.3	< 0.4	< 0.5	< 0.75
Global	28.4	51.3	75.5	87.1	93.5	97.4	99.97

Relative fraction of data (%) with DOP(670 nm) < X (fractional):							
Zone	< 0.05	< 0.1	< 0.2	< 0.3	< 0.4	< 0.5	< 0.75
Global	41.8	65.6	83.4	91.9	96.3	98.6	99.96

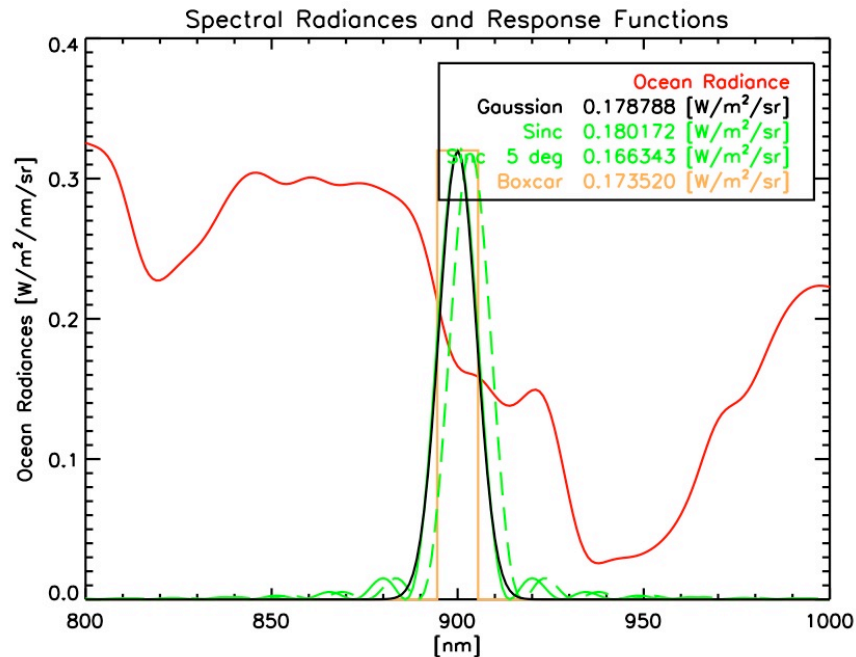
Relative fraction of data (%) with DOP(865 nm) < X (fractional):							
Zone	< 0.05	< 0.1	< 0.2	< 0.3	< 0.40	< 0.5	< 0.75
Global	58.8	75.2	87.7	94.3	97.7	99.3	99.98

CLARREO Polarization Needs for Inter-Calibrations

- A polarimeter can inter-calibrate other on-orbit instruments' polarization sensitivity...
 - ...If sufficient identical look angles of differing polarization state scenes can be viewed
 - Selection of scenes with little polarization simplifies radiometric cross-calibration without need for polarimetry
- *Polarimetric inter-calibration does not reduce radiometric uncertainty due to polarization sensitivity of other instrument when viewing scenes of unknown polarization states*
 - *Polarimetric inter-calibration helps estimate radiometric uncertainty from other instrument*

Shortwave Inter-Calibration to Other On-Orbit Instruments

- Limited by knowledge of other instrument's spectral response function



$$\sigma^2 = \sigma_r^2 + \sigma_\lambda^2 + \sigma_p^2 + \sigma_{spatial}^2$$

Radiometric uncertainty from CLARREO

$$\sigma_r \approx 0.2\%$$

Spectral response function uncertainty

$$\begin{aligned} \sigma_\lambda &\propto \Delta\lambda_{CLARREO} / \Delta\lambda_{cal_instrument} \\ &\approx 5\% \times \Delta\lambda_{CLARREO} / \Delta\lambda_{cal_instrument} \end{aligned}$$

Polarization uncertainty

$$\sigma_p \approx (\text{scene polarization}) \times (\text{instrument polarization sensitivity})$$

$$\sigma_p \approx 20\% \times 2\% \approx 0.4\%$$

Inter-Calibrations Have Differing Requirements From Climate Benchmarking

Requirement	Climate Benchmarking	Inter-Calibration
Radiometry	0.3%	~0.5% (may not be limiting factor)
Spectral Resolution	~10 nm	2 - 10 nm
Spectral Range	continuous	continuous
Spatial Resolution	~1 km	~1 km
Spatial Range	100 km	100 km
Polarimetry	minimize for radiometry via optical design	helpful to estimate radiometric uncertainties
Orbit	Sun-Sync or Low Lat.	Precessing

CLARREO SW Instrument Concepts for Full Spectral Range

1. IIP instrument covers 300-1050 nm with 10 nm resolution
 - Supplement with 2nd NIR instrument to extend to 2500
 - Polarization sensitivity at center $\sim 0.2\%$
2. Broadband FPA covers 350-2500 nm with >3 nm resolution
 - Single instrument for entire range improves mass, power, co-registration
 - Sacrifice field of view ($\sim 10^\circ$) and long wavelength spectral resolution
 - Polarization sensitivity at center $\sim 0.3\%$
3. Build ~ 2 nm resolution spectrograph
 - Two spectrographs
 - Split after telescope and spectrograph slit
 - Sacrifices radiometric accuracy (signal/noise) and field of view
4. Build polarimetric radiometer with continuous spectral coverage
 - Likely doubles instrument (two telescopes plus four spectrographs) to maintain radiometry, field of view, spatial resolution, and full spectral coverage and resolution